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Bunch Shape Measurement of 181 MeV Beam in J-PARC Linac

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In J-PARC Linac, an energy upgrade project has started since 2009 using Annular-ring Coupled Structure Linac (ACS) cavities. We have decided to use the bunch shape monitors (BSM) as the monitors of the longitudinal beam width measurement in order to take the longitudinal matching using two bunchres located in the upstream of ACS cavities, where the RF frequency jumps from 324 to 972 MHz. Three BSMs were completely fabricated and installed in the original beam line. The BSMs were commissioned with the beam and their operability was demonstrated. In this paper, we introduce the mechanism of the BSM, its operability, the measurement results with the 181 MeV beam and consistency check with the respect cavity amplitude. We also describe the operational vacuum conditions and the outline of the improvement of the vacuum system for the BSMs.

KEYWORDS: Linac, Bunch Shape Monitor, Structure, Longitudinal Beam Width, Beam Commissioning

1. Introduction

The J-PARC Linac originally consists of a 50-keV negative hydrogen ion source, 3-MeV RFQ (Radio Frequency Quadrupole Linac), 50-MeV DTL (Drift Tube Linac), and 181-MeV SDTL (Separated-type DTL). We had two SDTL-type debunchers allocated at a the downstream of SDTL section and L3BT (Linac to 3-GeV RCS Beam Transport). The operating frequency for these accelerating cavities and bunch repetition are 324 MHz [1-2]. In the energy upgrade project in which the output energy is increased from 181 MeV to 400 MeV, additional 21 ACS (Annular-Coupled Structure Linac) cavities were newly installed in the original beam transport part in the downstream of SDTL section. To meet with this project, the beam instruments for the ACS and downstream beam transport section for the beam commissioning were newly designed and fabricated. Because the operating frequency is 972 MHz of the ACS with three-fold frequency jump from that of the SDTL, and the longitudinal mismatching would increase at the position of frequency jump, we need to take matching at the upstream of new ACS section using two buncher cavities which are the ACS type buncher cavities. We have decided to use the bunch shape monitors (BSMs) as the longitudinal beam width monitors for the longitudinal beam width measurement. We started the fabrication of three BSMs under corroboration with INR (Institute for

Nuclear Research, Russia). The development of the BSMs began back in 2009 and was completed at the end of March, 2012. All three BSMs were successfully installed in the summer shutdown of 2012. The BSMs were commissioned with the beam and their operability was demonstrated. Along with the BSM measurements, we have encountered the problems. The problem involves the degradation of the vacuum conditions during the measurement. Presently, we have postponed the longitudinal matching using BSMs because of this problem. Vacuum conditioning with outgas analysis have been performed to avoid the vacuum degradation. The new vacuum system is additionally attached for the BSMs. After the summer shutdown that ranged for July to September, 2014, we try to use the BSMs with new vacuum system for the longitudinal width measurement of J-PARC Linac. This paper describes the principle and mechanism of BSM, problems that were faced during the operation and it operability. In addition, we introduce the outline of new vacuum systems for the BSMs.

2. Bunch Shape Monitor for J-PARC Linac

2.1 Principle of longitudinal width measurement

A device for the longitudinal beam width measurement is designed, based on the observation of secondary electrons emitted from a single wire intersecting the beam as shown in fig. 1[3]. The series of bunches of the beam under measurement intersects the target wire with 0.1 mm diameter and the low energy secondary electrons are emitted out from the wire. The wire is held on a negative potential of typically 10 kV. The emitted secondary electrons are moved almost radially toward a thin collimator. A fraction of the electrons passes through input collimator and enters RF deflector opening at a frequency equal to the Linac accelerating field frequency (324 MHz). Deflection of the electrons at the exit of the RF deflector depends on their phase with respect to deflecting field, where an RF-field is applied having the same frequency as the accelerating RF. Downstream of the drift distance the electrons are spatially separated and their coordinates are dependent on phase of the deflecting field. Adjusting the deflecting field phase with respect to accelerator RF reference, one can obtain a longitudinal width of charge in the bunches of the analyzed beam. For a fixed collimator position, the phase of the deflecting RF relative to the accelerating RF can be changed to transmit electrons representing different time slots of the beam bunches, to get a full image of the bunch structure. The resolution of this device is better than 1 degree in phase. It is known that the emission of secondary electrons is a fast process with a time difference of less than 1 ps between the hit of the

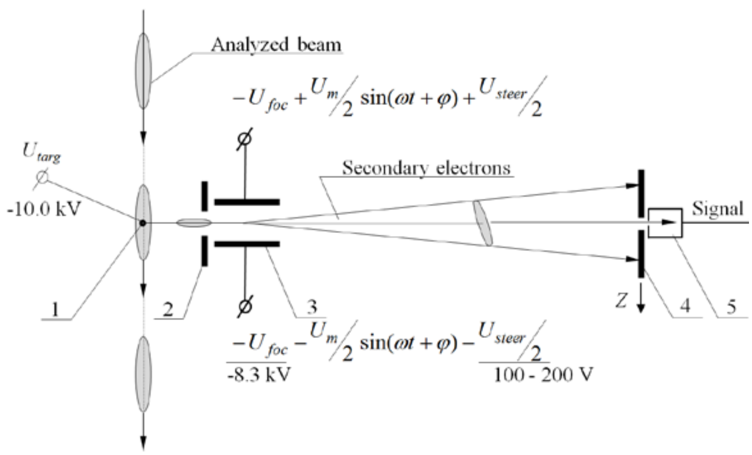


Fig. 1. Principal of BSM (1-target wire, 2-input collimator, 3-RF deflector, 4-output collimator, 5-electron collector)[3].

beam particles and the electron emission, i.e., the emission of secondary electrons is much faster than the required resolution. In addition, the electrons have to be focused transversally.

2.2 Configurations of monitor

BSM consists of the body, RF deflector, steering magnet, actuator and electron detector in fig. 2. BSM body is designed to be installed between the quadrupole doublets whose spacing reaches only 90 mm for the beam axis. An RF deflector and an actuator which holds a target wire are vertically installed against the beam axis on the body. Secondary electron past through the doubly installed collimators on the RF deflector travels to the pipe connected to the electron detector.

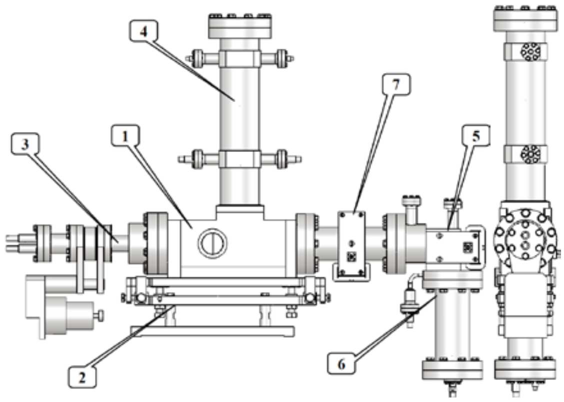


Fig. 2. BSM outline (1- body, 2- support, 3- target actuator, 4- RF deflector, 5- bending magnet, 6- electron detector, 7- steering magnet).

The configuration of RF deflector is shown in fig. 3. RF deflector arranges a pair of electrodes whose length is adjusted λ/2 (λ: wave length of the acceleration frequency of 324 MHz) in parallel. In addition, we apply the constant DC voltage to focus the secondary electron trajectories from the feed-through set. There are collimators in the both sides of deflector pipe and spacers to support the electrodes spacing in the pipe. These structural characteristics depend on the low conductance of pumping rate.

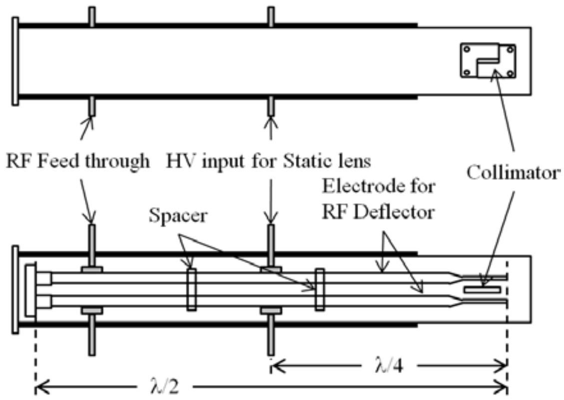


Fig. 3. Schematic view of RF deflector. Top is the surface of deflector and the bottom is the inside of deflector. These figures are rotated with 9.

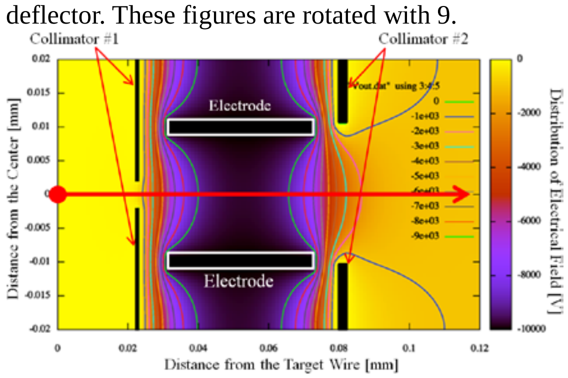
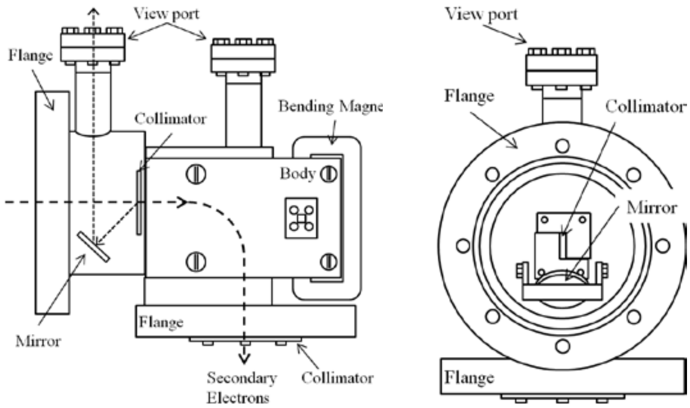


Fig. 4. The electrical filed inside the BSM. Bias voltage for the electrodes are negative.

Target wire is movable by an actuator which is driven by the stepping motor in the vacuum chamber with the minimum precision with 0.50 μm. so the bunch shape can be measured for different horizontal locations and it is possible to do a measurement with a high current beam by intercepting the beam edge with low power deposition. This precision is enough for the measurement because an RMS transverse beam size is 2.0 to 3.0 mm.

For the coarse tuning of secondary electron trajectories, we can directory observe the electron trajectory from the two view port. We use the thermal electrons emitted from the target wire by applying the electrical current (up to 0.9 A). When the electron trajectory is out of double collimators in Fig. 4, collimators, electrons hit the fluorescent material and it releases the light of fluorescence. The path width inside the bending magnet is almost 10 mm with the collimators at the both sides. Finally, secondary electrons past through some collimators and bending magnet reach the electron multiplier.

As shown in fig. 2 to 4, there are some collimators and structural parts which prevent from the gas flow. This is thought to cause a bad vacuum conductance and a low pumping rate.



(a) Side view of bending magnet part. (b) View from the axis of secondary electron trajectory.

Fig. 4. Schematic view around bending magnet part. Dashed line in the side view shows the secondary electron trajectory.

2.3 Installation and layout

After completion of the BSM tests, the BSMs have been transported to the accelerator tunnel and installed in prescribed positions (fig. 6). Because two ACS type buncher cavities whose acceleration frequency is 972 MHz are knobs for the longitudinal width matching, we installed three BSMs in the upstream part of ACS section. In the original beam line, there was no acceleration cavity but quadrupoles were located periodically at the same position before and after upgrade.

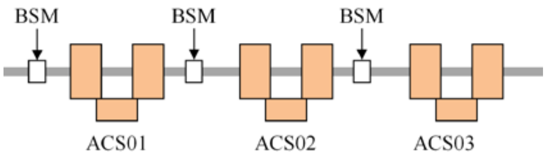


Fig. 5. Bunch shape monitor layout in the upstream part of ACS section. The orange squares represent the cavities and the white squares represent the BSMs with arrows.

3. Beam Commissioning

3.1 Parameter Survey

Before starting the measurements the BSMs must be tuned to find proper settings as the high voltage (HV) to the secondary electron multiplier, bending magnet, HV to electric static lens, steering magnets and the potential for the target. BSMs settings were found in laboratory tests and preliminary tests in beam line. And the wire position was tuned using beam with observing downstream beam loss, while the wire was inserted in the beam. The wire is set at the position of the highest beam loss detection is thought to be a beam center. And we scanned the electrical current of a steering magnet to search the highest peak of an electron multiplier signal. At the same time, we adjusted the proper bias voltage for the electron multiplier.

3.2 Vacuum Aggravation

Under the test measurements, several problems connected with the influence on the vacuum were found. The problem was aggravation of vacuum in case of multipactoring in the RF deflector at the operating mode. This discharge arises when the HV potential is applied to the deflector electrodes. The software was modified to suppress this effect. RF is switched on with the delay of 100 μs after applying HV and only during the measurements. Another effect is an influence of a dark electron current from the target. The electrons are accelerated and bombard the surfaces resulting in desorption of the absorbed gas molecules. The effect was observed in all three BSMs immediately after applying HV target potential. This effect can be minimized by the conditioning with HV, but this cannot be perfectly removed.

3.3 Initial Check

Test longitudinal beam width measurements were done with beam energy 181 MeV, peak current as 15 mA, pulse duration as 100 μs and pulse repetition rate as 1 Hz. We estimated the consistency of the RMS phase width among BSM's could be seen with turning off the cavity in front of the BSMs. We change the SDTL15 amplitude while setting its synchronous phase to -90 deg. We measure the response of each monitor with respect to the SDTL15 amplitude. In this situation, the larger beam width was estimated at the downstream monitor positions using 3D-PIC simulation.

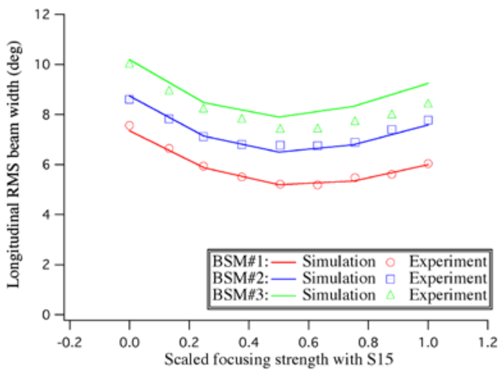


Fig. 6. Measured longitudinal RMS beam width with changing focusing strength of last SDTL cavity (S15) and corresponding simulation results [5].

Fig. 6 shows the measured dependence and simulation results. It is readily seen in this figure that the experimentally obtained phase width dependence agrees with the simulation for the BSM#1 and #2. However, the result for the BSM#3 shows some discrepancy, we need further study on it.

3.4 First Measurement of Longitudinal Bunch Width

First data acquisition was conducted after above consistency check and the transverse matching. Because of the pulse duration as 100μs, the measurement range for the preceding 5μs and 20μs more after the pulse was set. First data taken by BSM#1 is shown in Fig. 7, the beam bunch is coming from the backside and the feed forward delayed can be seen around the backside. The noisy electrons are also coming into the SED, grand level is increased around the bunch tail. The dynamic range of the monitor is 1.0e-3 in the figure. The range is enough for the calculation of RMS bunch

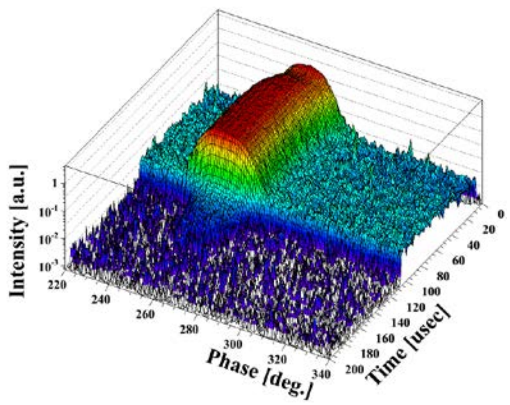


Fig. 7. First longitudinal width measurement data of BSM#1. Beam bunch is coming from backside.

width, but smaller noise level would be required to maintain the higher calculation accuracy. Calculated RMS bunch width is 5.02 deg. from Fig. 7. Measured longitudinal bunch shape is not uniform and this would be effective for the calculated RMS bunch width. So we pick up the last half of the pulse to neglect the feed forward delay and suppress the half of large background. And the RMS width is calculated time by time and took averaging.

First data of bunch length of H^- exited from fifteen SDTL cavities were successfully obtained. Primary data was rigorously discussed with the beam simulation and the monitors started to be employed for the beam dynamics study.

In the space charge driven transverse-longitudinal coupling resonance study, we measured the longitudinal emittance with BSMs. The results will be contributed to the design of the beam operational parameters for the energy upgraded Linac. The high intensity Linac designs follow the "equipartitioning condition", a strict control of the transverse and longitudinal tune ratios throughout the Linac that ensures space-charge driven emittance exchange between the longitudinal and transverse planes is minimized as a tune ratio diagram (Hofmann's Charts). By the development of BSMs, an experimental study can be conducted, where for the first time we measured both the transverse and longitudinal emittance [4].

4. Summary

Three Bunch Shape Monitors (BSMs) have been developed and fabricated for J-PARC Linac at the Institute for Nuclear Research of the Russian Academy of Sciences. The BSMs had been assembled, installed in beam line. The BSMs had been commissioned with the beam and their operability has been demonstrated. The main BSM parameter-phase resolution was evaluated. Along with the measurement with BSM, several problems had been met. The first problem is the influence of quads magnetic fields on secondary electron trajectories. The problem has been overcome by installing magnetic shields. The influence of the shields on quads field was also estimated. The second problem is the influence of target HV potential on vacuum due to dark current resulting in absorbed gas molecules desorption in BSM#3. This effect was completely removed by the conditioning.

In the beam commissioning, BSMs were checked with the consistency and started to use the beam dynamics study.

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